Amorphous and Microcrystalline Silicon Solar Cells —A Status Review

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Outline

- Status of a-Si based PV
- Status of μc-Si based PV
- a-Si and μc-Si hybrid cells
- a-SiGe *vs* μc-Si as bottom cell--discussion
- Research progress at the Univ. of Toledo

a-Si, a-SiGe and μc-Si

Material	Eg (eV)	thickness needed for J_{sc}= 25 mA/cm^2	Typical deposition rate (A/s)			
			RF PECVD	VHF PECVD	MW PECVD	HW CVD
a-Si	1.7	--	3	20	100	100
a-SiGe	1.4*	~0.2 um	3	20	100	100
μc-Si	1.1	~2.0 um	0.3	2	10	10

a-Si based small area solar cells

Structure	Initial η (%)	Stable η (%)	Organization
a-Si/a-SiGe/a-SiGe	15.2	13.0	United Solar
a-Si/a-SiGe/a-SiGe	11.7	11.0	Fuji
a-Si/a-SiGe/a-SiGe	12.5	10.7	U. Toledo
a-Si/a-SiGe/a-SiGe		10.2	Sharp
a-Si/a-SiGe	11.6	10.6	BP Solar
a-Si/a-SiGe		10.6	Sanyo
a-Si/a-SiGe		12.4	United Solar
a-SiGe	12.5	10.4	U. Toledo

a-Si based PV modules

Structure	Stable η (%)	Size (m^2)	Company
R&D modules			
a-Si/a-SiGe/a-SiGe	10.7	0.09	United Solar
a-Si/a-SiGe	9.1	0.08	BP Solar
a-Si/a-SiGe	9.5	0.12	Sanyo
Large-area Modules			
a-Si/a-SiGe	9.3	0.52	Sanyo
a-Si/a-SiGe/a-SiGe	9.0	0.32	Fuji
a-Si/a-SiGe	8.1	0.36	BP Solar
a-Si/a-SiGe/a-SiGe	7.9	0.45	United Solar
a-Si/a-Si/a-SiGe	7.8	0.39	ECD

μc-Si based solar cells

Structure	Initial η (%)	Stable η (%)	Organization
a-Si/μc-Si		12.0	Neuchatel
a-Si/μc-Si		11.2	Julich
a-Si/μc-Si	13	11.1	United Solar
a-Si/μc-Si	13.0	11.5	Canon
a-Si/μc-Si/μc-Si	12.3	11.5	Kaneka
a-Si/a-SiGe/μc-Si	11.4	10.7	ECD

μc-Si PV modules

Structure	Initial η (%)	Size (m^2)	Company	μc-Si dep. Rate (A/s)
a-Si/μc-Si	9.2	0.068	Julich	5
a-Si/μc-Si/μc-Si	13.2	0.08	Canon	10-30
a-Si/μc-Si	13	0.4	Kaneka	11
a-Si/μc-Si	11.2	1	Kaneka	11

μc-Si vs a-SiGe as Narrow Bandgap (NBG) cell in multijunction two-terminal stack

Analysis and Comparison in terms of

- Multijunction cell design consideration
- Manufacturing cost
- Raw material availability
- Easiness in scaling up into high volume production
- Potential for further improvement in efficiency

Multijunction μc-Si Cell Design Considerations

Issues related to a-Si/μc-Si tandem cell

- Best μc-Si cell today: Voc ~ 0.52 V, Jsc ~ 26 mA/cm^2.
- Cell matching requires a-Si top cell to have 13 mA/cm^2
- Without benefit of BR, a-Si i-layer thickness needs to be > 4000 A
  >>Light degradation problem

Neuchatel approach:

- make i-layer at higher Ts >> allows d down to 3000A
- make ZnO semireflective layer >> allows d to decrease further

Multijunction μc-Si Cell Design Considerations—Con'd

Issues related to a-Si/μc-Si/μc-Si triple cell

- Requirement on top cell current relaxed
- Middle cell Voc too low

Issues related to a-Si/a-SiGe/μc-Si triple cell

- Requirement for top cell current relaxed
- Minimal GeH4 used for middle cell
- a-SiGe middle cell can be made with high Voc and FF
- light degradation less than a-Si/μc-Si tandem

Manufacturing Issues

μc-Si	2μm	@15 A/s	→ 22 min
a-SiGe	0.2μm	@3 A/s	→ 11 min

Longer deposition time requires large capital investment for the production equipment

Need 30A/s for deposition of high quality μc-Si to complete μc-Si deposition in the same time

Raw Materials

μc-Si	uses	silicon	abundant, clean
a-SiGe	uses	germane	less abundant, toxic, a concern during manufacturing

Potential for further efficiency improvement

--Major Challenges to achieve low-cost, 16% stable cells

a-SiGe based cells

Need stable, narrower bandgap (1.3eV) material

Need to improve FF for bottom cell

Need higher deposition rate (10A/s) to reduce cost

Need stability under light

μc-Si based cells

Need to increase Jsc beyond 26 mA/cm^2

Need to finish the μc-Si layer deposition faster.

--thickness/deposition rate < 10 min

Need stable a-Si cell with Jsc >> 13 mA/cm^2

Recent Development at UT in High-efficiency a-Si Solar Cell Research

Supported by NREL Thin Film Partnership Program

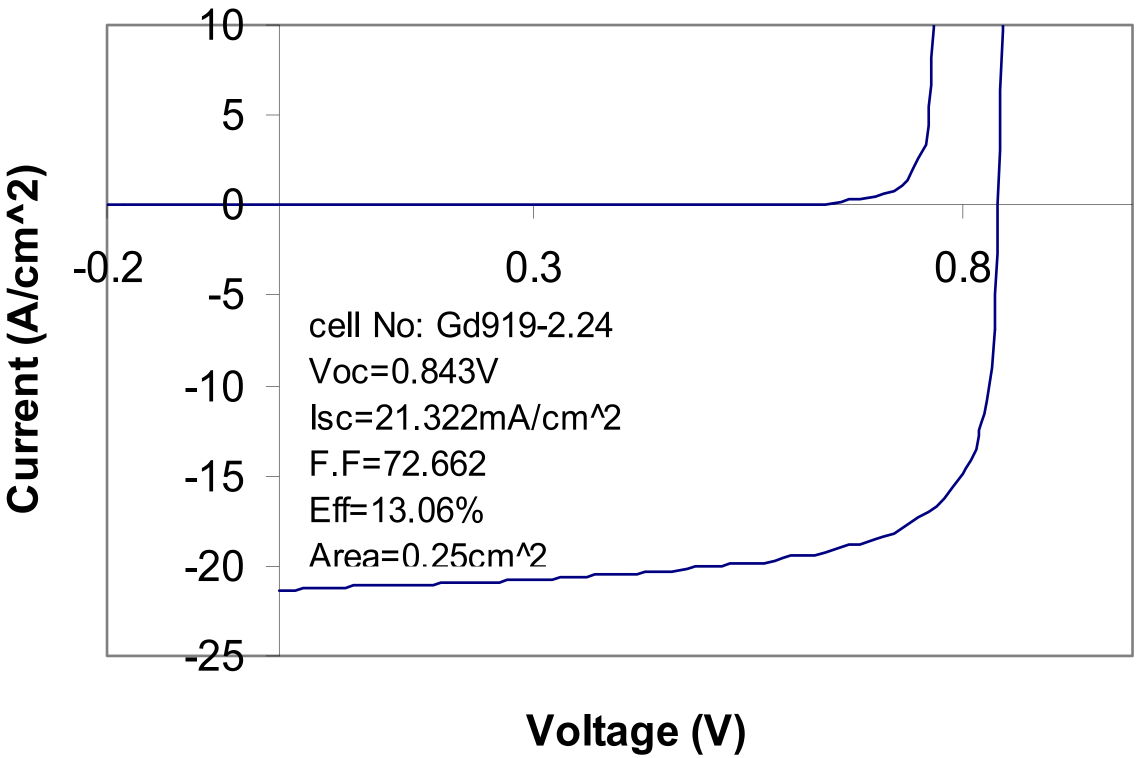
Program Objectives:

- High stabilized efficiency
- High deposition rate

Outline

- High Efficiency SJ a-SiGe Cell
- Optimization of Top Component Cell
- Optimization of Tunnel Junction
- Optimization of Triple-junction solar cells
- High Rate Deposition of a-Si Using Hot-Wire CVD

High Efficiency Single-junction a-SiGe Cell

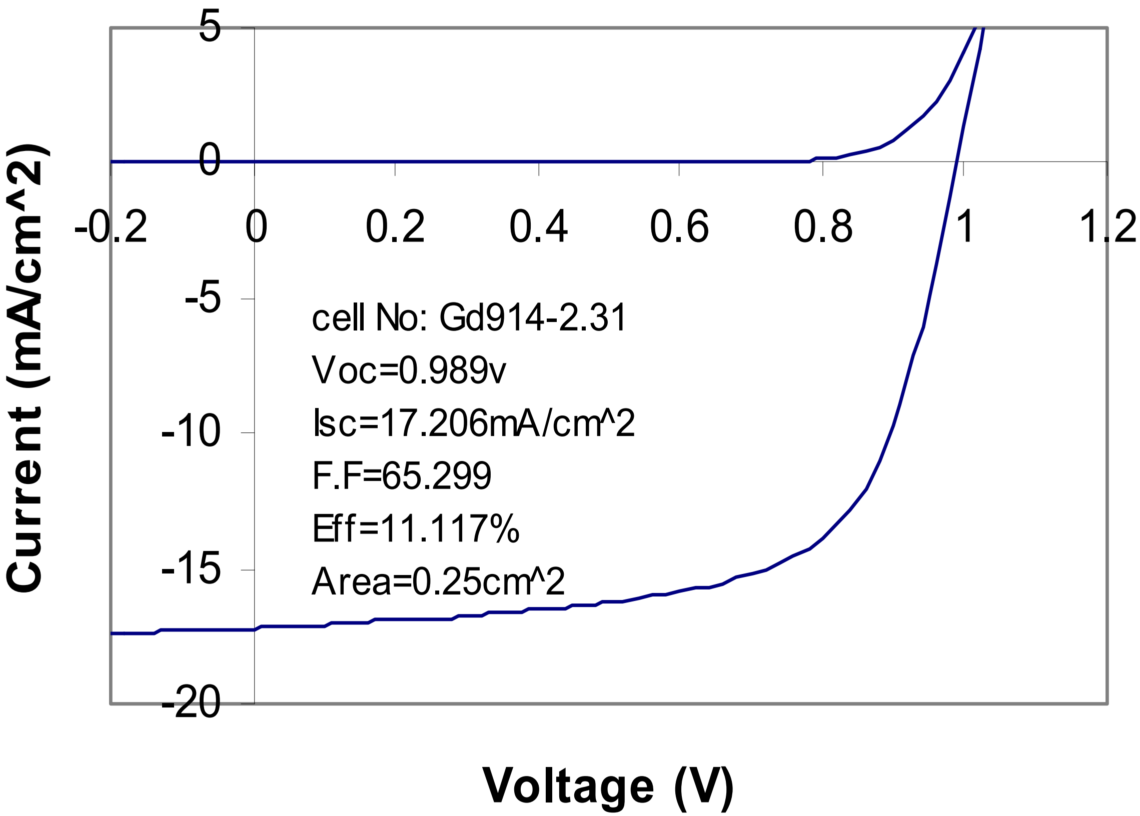


Initial η =13% for a-SiGe single-junction cell

Stabilized η =10.4% after 2500 hours of 1 sun light soaking

High-efficiency single-junction a-SiGe solar cells are obtained using a p-layer deposited with two separate steps: with one at a higher temperature for better interface with a-SiGe i-layer and other at a lower temperature for better transmission. We achieved a-SiGe single-junction cells with greater than 12.5% initial efficiency and 10.4% stabilized efficiency.

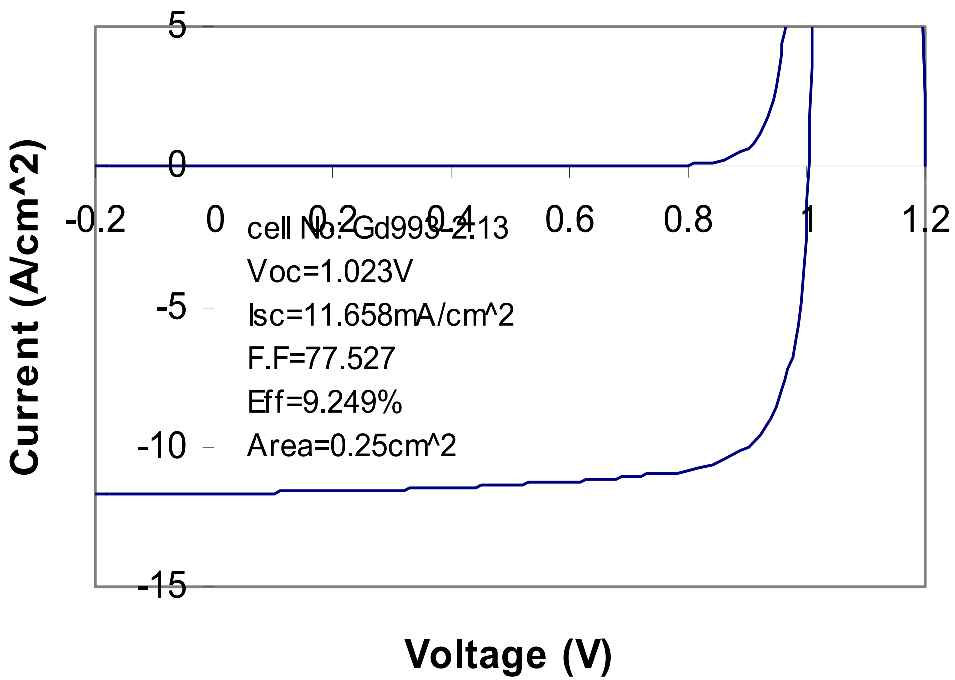
Optimization of Top Cell



Single-junction a-Si top cell

Initial η = 11.1%

Optimization of Top Cell - Con'd



Single-junction a-Si top cell:

V_{oc} = 1.023 V
FF = 78%

Jsc = 11.7 mA/cm2
Initial η = 9.25%

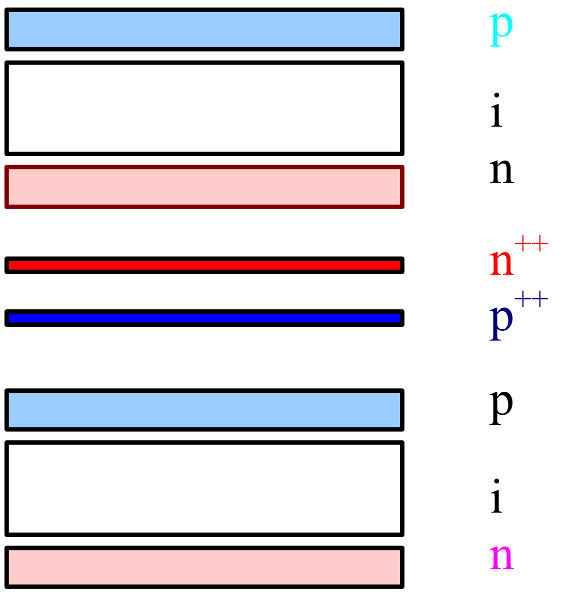
Ideal for use as top cell

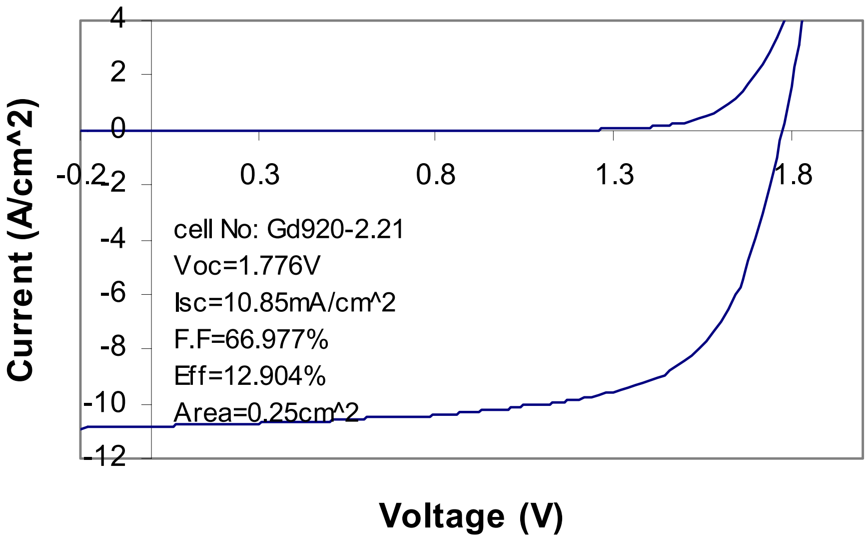
In summary, by optimizing p-layer and i-layer, we obtained improved top cell:

- Wide bandgap a-Si top cell with 11.1% initial efficiency
- Wide bandgap a-Si top cell with 1.023V Voc and 78% FF

Optimization of Tunnel Junction in Tandem Cells

Sample No	P^{++} time	BF_3/SiH_4	N^{++} time	PH_3/SiH_4	Voc (V)	Jsc (mA/cm^2)	FF (%)	η (%)
gd920	10"	1.5	10"	1	1.778	10.9	66.7	12.9
gd950	15"	3	15"	2	1.777	9.7	68.6	11.9
gd953	20"	3	20"	2	1.77	9.7	66.9	11.5

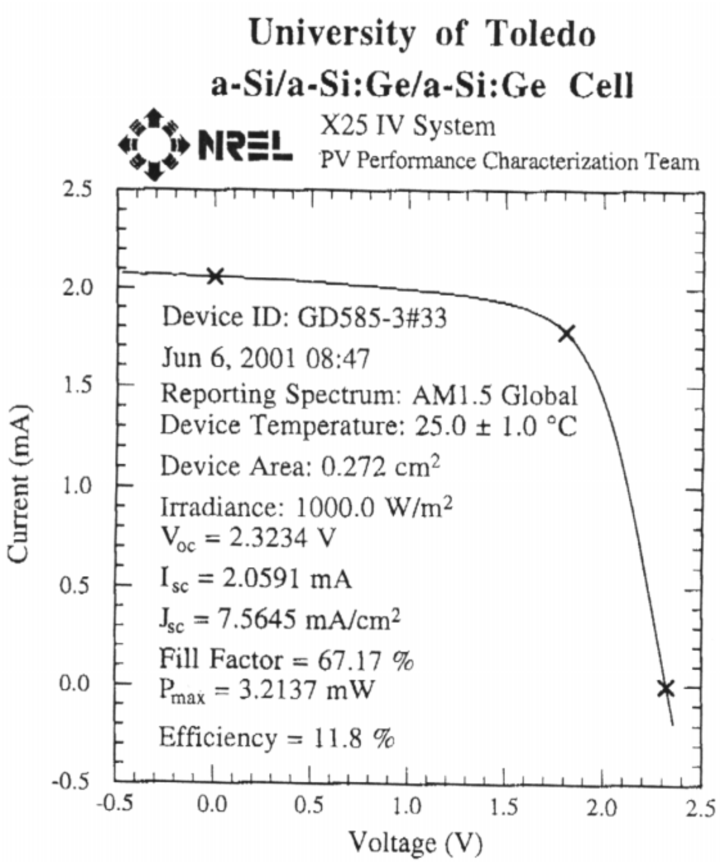




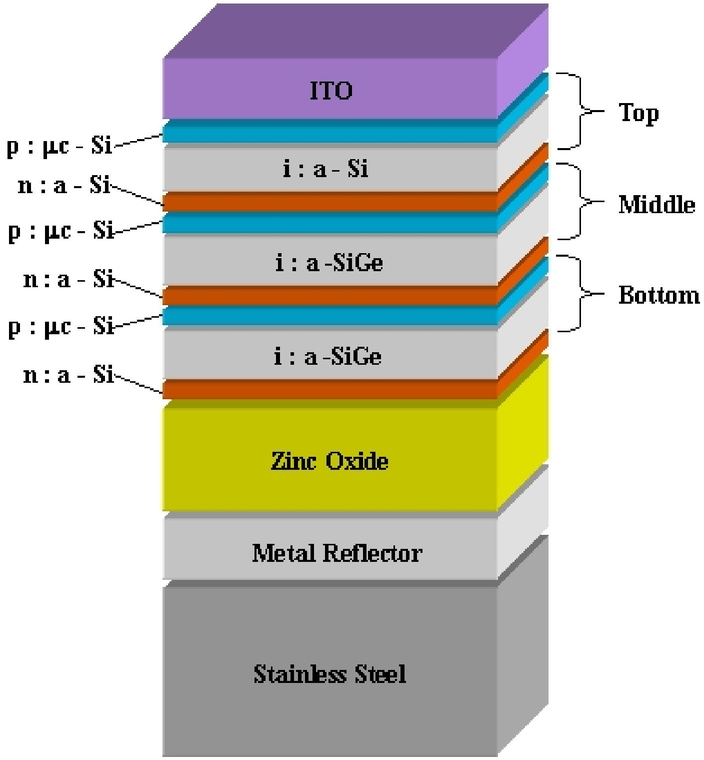
Conclusion:

- Optimized heavily doped interface layer
- Optimized doping and thickness of doped layers at the tunnel junction
- Achieved tandem solar cells with initial efficiency around 12.5%.

Optimization of Triple-junction Solar Cells



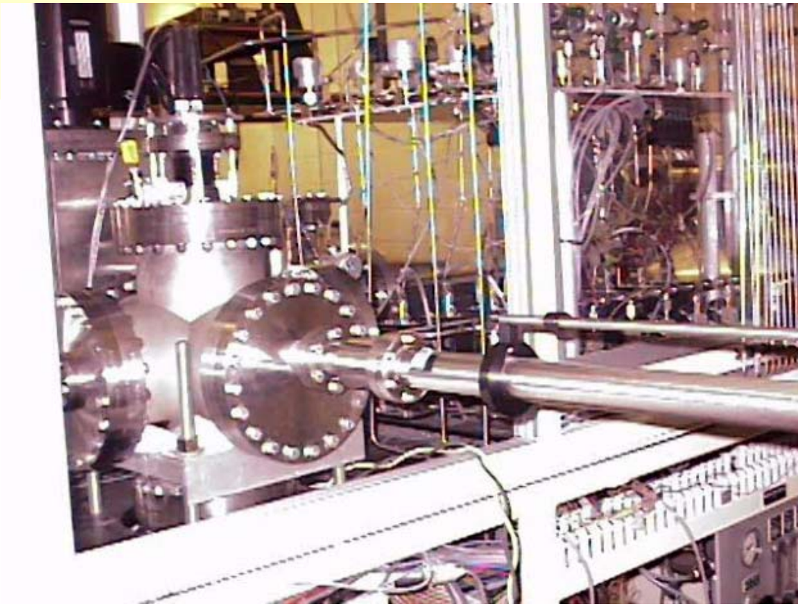
Earlier results



11.8% initial, total-area efficiency

(12.5% initial, active-area efficiency)

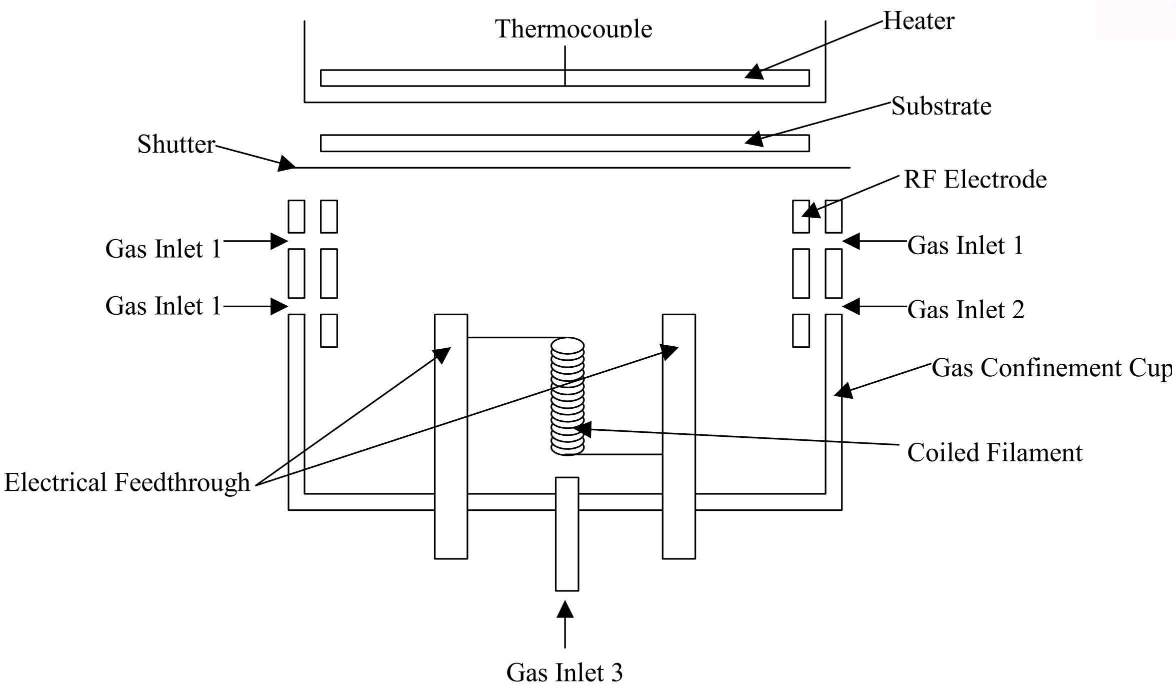
High Rate Deposition of a-Si Using Hot-Wire CVD



HWCVD integrated into 3-chamber PECVD system

Objective:

- High-rate depositoin of a-Si and a-SiGe
- High rate deposition of uc-Si



High-rate deposition of a-Si using HWCVD - Con’d

Sample	Si_2H_6 flow (sccm)	H_2 flow (sccm)	T_{sub} (°C)	Time (sec)	Thickness (μm)	Dep Rate (Å/s)	n	E_g(opt) (eV)	hydrogen (at %)	R*	Sample ID
A1	105	0	100+	30	2.1	700	1.9	~1.9	>10	1.0	HW107
A2	105	0	200+	30	1.4	460	2.3	1.74	12	0.90	HW113
A3	105	0	300+	30	0.72	240	3.6	1.63	10	0.17	HW112
A4	105	0	400+	30	0.72	240	3.7	1.61	6	0.11	HW111
B2	105	100	200+	30	0.54	180	3.6	1.78	19	0.50	HW108
B3	105	100	300+	30	0.60	200	3.9	1.62	7	0.04	HW109
B4	105	100	400+	30	0.46	150	4.3	1.63	3	0.05	HW110
C	70	0	175+	120	2.4	200	3.6	1.63	8	0.36	HW105
D	140	0	100+	30	2.4	800	1.6	~1.9	>8	1.0	HW106

Note: All samples are deposited with T_{fil}=2000C in this Table.

Summary:

- Dense, a-Si films are deposited at 240 A/s at high Ts. Films show mostly monohydride bonding from IR.
- Porous a-Si films are deposited at 700-800 A/s at low Ts (=100C). IR shows 100% 2100 cm^{-1} stretching absorption.
- Effort in trying to make solar cells using HW-deposited a-Si i-layers is hindered by device shorting.

Summary for UT a-Si Photovoltaic Research

UT has produced high efficiency a-Si solar cells:

- Single-junction cells
- Dual junction solar cells
- Triple-junction solar cells

All with > 12.5% initial efficiency and

All with > 10% stabilized efficiency